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Method for determining and controlling the material flow of continuous-cast slabs

A Background of The invention

~~Description~~

Field of the Invention

The invention relates to a method for determining and controlling the material flow of continuous-cast slabs, in particular steel slabs, by monitoring and optimizing the temperature on their transport path between the continuous-casting installation and the rolling mill.

A Desciption of the Prior Art

For the operator of a continuous-casting installation with a connected rolling mill, and ~~for~~ projecting slab continuous-casting finishing bays as a link between the continuous-casting installation and the rolling mill, it is becoming increasingly important to know the heat content which is present in the slab which has just been cast or is being temporarily stored, in order to bring the slab into a material flow which corresponds to the heat content still present therein in an economical optimum manner. Since a slab which has just been cast has an inhomogeneous temperature profile which, over a prolonged period, strives to achieve a more homogenous temperature profile, it is not possible to draw conclusions about the mean slab temperature using measurable surface temperatures. Therefore, it is also impossible to be certain of the slab temperature profile

after a certain time, for example in order to bring the slab to an optimum, homogenous rolling temperature via a reheating fixture. Finally, the solidified slab which leaves the caster passes through different transport and processing paths, which each lead to different slab temperature profiles. Differences in the temperature profile arise depending on whether the slab is transported on a roller table with or without thermal insulation, whether one or more slabs are stored in the stack, whether the slabs are stored in an open slab yard or in an open or closed holding pit. Different temperature profiles also result for slabs which have undergone accelerated cooling in a water immersion basin compared to those which have undergone slower cooling in a water-spraying installation. It is therefore clear that it is desirable to find and be aware of the cooling profile of the various slabs, in order to use this knowledge in a targeted manner for material monitoring and controlling the material flow, which were hitherto carried out predominantly on the basis of experience and tests.

Summary of The Invention

In view of the above problems, the object of the present invention is to find a method for determining and controlling the material flow of continuous-cast slabs, in particular steel slabs, which enables the amount of heat and the temperature profile of a continuous-cast slab on its path between the continuous-casting installation and the rolling mill to be determined and used in a targeted manner, ~~in order~~

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A1 ~~for the values~~ The found to be used in an existing slab-monitoring system~~, in order~~ to obtain a material flow which is optimum in terms of energy, i.e. is economical and safe.

To achieve the object, it is proposed, according to the invention, that ~~to determine~~ the amount of heat and the temperature profile of the ~~slab~~ slab is determined by, starting from the known temperature of the liquid phase at the mold exit of the continuous-casting installation and given knowledge of the physical parameters of the slab, calculating the convective mixing of the amount of heat contained in the slab and the time-dependent heat loss from the inhomogeneously cooling slab to the surrounding medium ~~are calculated~~ by means of a mathematical-physical model, and using the result of the calculation, if appropriate together with the measured surface temperature of the slab, ~~is used~~ to control the material flow in an existing slab-monitoring system.

The proposal of the invention makes it possible to guide a slab in a controlled manner through the various material flows, such as warm charge rolling, hot charge rolling, cold charge rolling or hot direct rolling, from the continuous-casting installation into the rolling mill. It is possible both to find the cooling profile of various slabs in the stack and to determine the profile of cooling at the surface of various slabs, in order to draw a conclusion concerning the temperature in the interior of the slab using

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control measurements. The calculated values and additional production data of the installation can be used, for example, to determine the size of the holding pit and, in operation, to predict hot batches at different mean temperatures.

In a preferred configuration of the method according to the invention, a ~~there is provision for the~~ two-dimensional finite element method may ~~to~~ be used to calculate the mathematical-physical model. Finite element calculation methods enable a very wide range of operations to be simulated, thus assisting with design developments, handling operations, sales and, in the present case, also the future plant operator. In the finite element calculation design phase, the method is frequently used to reveal and minimize possible risks through structural mechanics analyses. It can be used to carry out deformation and stress analyses, temperature calculations, thermomechanical simulations and also to determine eigenfrequencies and eigenforms, with the finite element calculations aim of structural optimization. Simulations based on finite element calculations are often demanded by plant operators as early as the project phase and are frequently included in the supply contract of the plant as a fixed component of the contract.

Calculations using the finite element method are also carried out during the development of mathematical-physical models which have to provide accurate results on-line within

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a very short time, predominantly parameter studies, from the results of which analytic formulae are then derived.

A27 In ~~For the~~ present invention may comprise the two-dimensional finite element method, the finite difference method or software using formulae derived from off-line studies are used to calculate the mathematical-physical model.

A universal, commercially available finite element package can be used in off-line studies to implement the method. However ~~On line~~, this package is probably too large and too slow for use on-line. Therefore, it is appropriate to use, i.e. program, a method (this may also be a finite element method or the finite difference method) which is specifically adapted to the slab geometry (rectangular) and is therefore quick enough to use on-line. The on-line method can be checked using the off-line finite element package.

The physical parameters of the slab used are preferably the temperature-dependent material values density ρ, the specific heat c_p, the thermal conductivity λ and scale properties.

According to the invention, to optimize the method, the result of the calculation and the measured surface temperature of the slab are linked to automation of the material flow in the slab-monitoring system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention advantageously makes it possible, by means of the mathematical-physical model which preferably ~~using~~ uses a finite element simulation or finite difference method, to

determine the temperature profile of slabs and stacks of slabs of different dimensions under specific cooling conditions. Through evaluation of the profiles of the mean slab temperature and selected surface temperatures over time, it is subsequently possible to estimate ~~make a good estimation of~~ the mean slab temperatures by measuring the surface temperature. For example, the result of the method according to the present invention may ~~can~~ be used to determine ~~draw conclusions as to~~ how many hours a fixed mean slab temperature is maintained in the finishing bay. Further it is possible to determine ~~draw conclusions concerning~~ the entire temperature spectrum in the slab-monitoring system. It has emerged that the method according to the invention and the above-described calculation method are very flexible in use and are suitable for achieving the object of the invention, i.e. that of enabling economical and reliable material flow between the continuous-casting installation and the rolling mill. The invention Replaces ~~is able to replace~~ the previous slab control method which was based on experience and empirical values. The continuous-casting installations no longer have to be overdimensioned for safety reasons, because with the method according to the present invention it is now possible to determine and control the actual conditions for the material flow between continuous-casting installation and rolling mill.

The inventive method ~~invention~~ is easiest to explain with reference to a practical example. In the example, it is assumed that a plurality of continuous-cast slabs are stored in a stack in

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an open holding pit. The mean cooling profile of the various slabs in the stack is to be determined, as is the profile of cooling at the surfaces of various slabs in the stack. The inventive method may be used ~~aim of an application could be~~ to determine the size of a holding pit or to predict hot batches of slabs at different mean temperatures during ongoing production.

Working on the basis of a model as described above, the ~~by way of~~ example includes thirteen slabs each with 420 discrete elements. ~~are discretized~~. It is sufficient to model one half of a slab given symmetrical boundary conditions and, for example, to generate the finite element network in such a way that the mean temperature and the time-dependent control of the stacking operation can subsequently be determined with ease.

The simulation can be divided up as follows:

1. Monitoring of the temperature of the slab cross section as it passes through the caster, corresponding to the starting temperature profile for each individual slab at the start of the stack.
2. Simulation of the stack of the individual slabs.
3. Simulation of the cooling of the stack of slabs.

In the first substep, the solidification of the slab in the caster is simulated in order to generate an entry temperature profile of the slabs in the holding pit which ~~is close to reality~~ approximates the actual value. The material density, specific heat and thermal conductivity are temperature-dependent.

In the liquid phase, there is also convective heat exchange, but this was not modeled. In order nevertheless to simulate the temperature homogenization on the basis of the convective mixing, instead the thermal conductivity was increased by a factor of 100 compared to the solid phase. The various water cooling operations in the areas of the primary and secondary cooling zones represent important boundary conditions. The temperature range of possible surface temperatures is divided into sections of various heat transfer types (stable film evaporation, unstable area, burn-out point, etc.) on the basis of a heat transfer model, since different approaches apply with regard to the heat transfer coefficient for these areas. In some of these areas, the heat transfer coefficient is also dependent on the materials value of the surface of the cooling body, this applying, in the present case, in particular to highly oxidized surfaces, for which the materials values of scale are to be used.

The simulation of the stack of slabs begins with the introduction of the first slab into the holding pit. Thereafter, every 60 seconds the next slab is stacked on top of the previous slab. The stacking operation ends when a cold slab is laid on top of the twelve slabs which have hitherto been stacked. The inherent weight of the cold slab reduces the curvature of the top hot slab.

After the first slab has been introduced into the store, the corresponding discrete elements of this slab are activated, and the finite element simulation for this slab takes place as early as in the holding pit. The second slab follows, and the discrete elements of slab two are activated. This procedure continues in a similar manner until the final, cold slab is introduced into the store. The simulation of the entire stack of slabs in the holding pit then begins. Here as well, the heat transfer coefficients between the slab surfaces and the environment form significant boundary conditions. With the exception of the bottom support surface, heat transfer through air convection plus radiation is assumed for all surfaces of the stack of slabs.

The air convection is calculated using specific functions, since different heat transfer coefficients apply for the horizontal and vertical surfaces. At high temperatures, these coefficients are still low compared to the heat transfer coefficients of radiation, but at low temperatures the convection coefficients become dominant. Furthermore, the ambient temperature throughout the wider environment of the hall and the walls of the holding pit form part of the calculation. However, in a representative stack, these parameters can only be seen in a particular part of the solid angle, while in other parts of the solid angle there are adjacent stacks, which are at a similar temperature.

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The bottom horizontal surface of the stack is in contact with the pit floor. The pit floor itself could be included in the finite element calculation, but in a simplified version it is also possible to model the pit floor as a semi-infinite body which remains constantly at its starting temperature, at which there is then a time-dependent heat transfer coefficient.

For given slab dimensions, it is then possible to determine the temperature profile over the cross section of the slab or the stack of slabs. To be reintegrated into the material flow between caster and rolling mill, the mean temperature of a steel slab should lie between 500 and 600°C. At the start of cooling, the first slab still has the temperature profile corresponding to when it leaves the caster. At the end of the stacking operation, it is found that there is a more homogenous temperature distribution in the stack if the floor is appropriately well insulated. As a result of the cold slab being laid on top, the top slab in the stack loses a relatively large amount of heat in the first hour, and the bottom slab in the stack cools rapidly during a short initial period, until the floor acts as an insulator.

By linking a physical-mathematical model to the automation of a standard slab material flow, the method according to the invention makes it possible to control the individual slabs between continuous-casting installation and

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rolling mill in an economical and reliable manner. By carrying out control measurements on the surface of the slabs, including the values obtained through the calculation model, it is possible to draw conclusions as to the amount of heat and the temperature profile of the slab in a simple manner, provided that the appropriate boundary conditions are included. In this way it is possible to determine, at any location between continuous-casting installation and rolling mill and, in particular, in storage yards, how much heat is associated with the particular slab and what level of energy has to be supplied or dissipated in order to reach the temperature profiles which are optimum for the further process. The invention provides a design engineer with a means of designing the installation optimally, so that it is economical to produce and run.